

## Electric Power Steering Apparatus

### BACKGROUND OF THE INVENTION

#### Field of the Invention

5       The present invention relates to an electric power steering apparatus so configured as to transmit a driving force produced by an electric motor to a steering mechanism as a steering assist force.

#### 10 Description of Related Art

      Electric power steering apparatuses so configured as to perform steering assist by mechanically transmitting a driving force produced by an electric motor to a steering  
15 mechanism by a gear mechanism (a speed reduction mechanism) or a direct drive system have been conventionally employed.

      In such electric power steering apparatuses, assist characteristics for determining the  
20 relationship between a steering torque applied to a steering wheel and an assist torque target value given to the steering mechanism from the electric motor have been previously determined, and are stored in a memory as an assist map. The assist  
25 torque target value corresponding to the steering

torque is read out of the assist map, and the electric motor is driven and controlled on the basis of the read assist torque target value.

The assist characteristics are determined  
5 such that the larger the steering torque is, the larger the assist torque target value becomes, as shown in Fig. 7. A positive value is assigned to the steering torque with respect to a rightward steering direction, while a negative value is  
10 assigned to the steering torque with respect to a leftward steering direction, for example. The assist characteristics are so determined that a positive value of the assist torque target value corresponds to the steering torque taking the  
15 positive value, and a negative value of the assist torque target value corresponds to the steering torque taking the negative value.

When the assist torque target value is a positive value, such a steering assist force as  
20 to steer a steerable wheel rightward is exerted on the steering mechanism. Conversely, when the assist torque target value is a negative value, such a steering assist force as to steer a steerable wheel leftward is exerted on the  
25 steering mechanism. When the steering torque

takes a value in a dead zone in the vicinity of zero, the assist torque target value is made zero.

In such electric power steering apparatuses to which such assist characteristics are applied, 5 when return stroke steering for rotating a steering wheel toward a steering angle midpoint is done, such a steering feeling (a so-called spring feeling) that the steering wheel is returned to the steering angle midpoint strongly 10 than a driver intends is produced. That is, when return stroke steering is done, a steering torque is reduced and correspondingly, an assist force is reduced. Accordingly, the steering wheel is returned to the steering angle midpoint strongly 15 by an inverted input from the steerable wheel.

This problem can be solved by increasing the slope of an assist characteristics curve such that a larger assist torque target value is set with respect to the steering torque. In this case, 20 however, a responsive feeling at the time of forward stroke steering is degraded.

#### SUMMARY OF THE INVENTION

Therefore, the applicant of the present invention has proposed to correct reference assist 25 characteristics on the basis of a steering speed

in Japanese Patent Application NO. 2002-160061 previously filed, to provide an electric power steering apparatus so configured as to perform steering assist in accordance with corrected  
5 assist characteristics obtained by the correction.

In the electric power steering apparatus according to the prior application, reference assist characteristics are shifted along the axis  
10 of coordinates of a steering torque depending on a steering speed, thereby obtaining corrected assist characteristics. More specifically, the shifting direction and the shifting amount of the reference assist characteristics are variably set  
15 depending on the direction of the steering speed (equal to a steering direction) and the magnitude thereof, for example. For example, the corrected assist characteristics are found by shifting the reference assist characteristics in the positive  
20 direction on the axis of the steering torque when the steering speed takes a positive value, while shifting the reference assist characteristics in the negative direction on the axis of the steering torque when the steering speed takes a negative  
25 value as well as determining the shifting amount

such that the shifting amount increases monotonously (for example, linearly) depending on the absolute value of the steering speed.

A motor driving target value is set in accordance with the corrected assist characteristics thus obtained, thereby making it possible to set assist characteristics which differ at the time of forward stroke steering and return stroke steering. Consequently, a sufficient responsive feeling can be obtained at the time of forward stroke steering, and a sufficient steering assist force is transmitted to a steering mechanism at the time of return stroke steering, thereby making it possible to cancel such an undesirable steering feeling (spring feeling) that a steering wheel is returned to a neutral position more strongly than a driver intends.

In such a configuration, however, the driver's steering effort on the steering wheel differs depending on the steering speed. Therefore, tuning for optimizing the reference assist characteristics for each vehicle type is difficult.

An object of the present invention is to

provide an electric power steering apparatus in which a good steering feeling can be realized, and reference assist characteristics are easy to tune.

An electronic power steering apparatus  
5 according to the present invention is an apparatus for performing steering assist by transmitting a driving force produced by an electronic motor to a steering mechanism. The apparatus comprises an operation amount sensor for sensing an operation  
10 amount of an operation member for steering a motor vehicle; a reference assist characteristics setting section for setting reference assist characteristics which are reference characteristics of a motor driving target value  
15 corresponding to the operation amount sensed by the operation amount sensor; a motor driving target value setting section for setting the motor driving target value corresponding to the operation amount sensed by the operation amount  
20 sensor in accordance with corrected assist characteristics obtained by shifting the reference assist characteristics set by the reference assist characteristics setting section along the axis of coordinates of the operation  
25 amount; and a motor driving section for driving

the electric motor on the basis of the motor driving target value set by the motor driving target value setting section. The apparatus further comprises a shifting amount setting  
5 section for setting, when forward stroke steering for operating the operation member in a direction away from a steering angle midpoint is done, the shifting amount of the corrected assist characteristics with respect to the reference  
10 assist characteristics to zero, while setting, when return stroke steering for operating the operation member toward the steering angle midpoint is done, the shifting amount of the corrected assist characteristics with respect to  
15 the reference assist characteristics to a value at which corrected assist characteristics is obtained in which the absolute value of the motor driving target value corresponding to the operation amount sensed by the operation amount  
20 sensor is increased.

According to the present invention, the corrected assist characteristics obtained by correcting the reference assist characteristics set by the reference assist characteristics  
25 setting section are applied to the operation

amount sensed by the operation amount sensor. That is, the motor driving target value is set in accordance with the corrected assist characteristics.

5        Although the reference assist characteristics are corrected by shifting the reference assist characteristics along the axis of coordinates of the operation amount, the shifting amount is determined such that the  
10        shifting amount is made zero at the time of forward stroke steering (at the time of steering in the direction away from the steering angle midpoint), and that the shifting amount is made a value corresponding to the corrected assist  
15        characteristics in which the absolute value of the motor driving target value is made larger than that in the case of the reference assist characteristics at the time of return stroke steering (at the time of steering in the direction  
20        nearer to the steering angle midpoint).

More specifically, there is provided a steering speed sensor, for example, for sensing a steering speed by the operation member, and the shifting direction and the shifting amount of the  
25        reference assist characteristics are variably set



depending on the direction of the steering speed (equal to a steering direction) sensed by the steering speed sensor and the magnitude thereof. For example, it is assumed that a steering torque  
5 sensed by a steering torque sensor which is an example of the operation amount sensor takes a positive value with respect to a rightward steering direction, while taking a negative value with respect to a leftward steering direction. In  
10 the reference assist characteristics, it is assumed that a positive value of the motor driving target value is assigned to the steering torque value taking the positive value, while a negative value of the motor driving target value is assigned  
15 to the steering torque value taking the negative value. Further, the steering speed takes a positive value with respect to the rightward steering direction, while taking a negative value with respect to the leftward steering direction.

20 In this case, in a case where the steering torque is not less than zero, for example, the shifting amount may be made zero when the steering speed takes a positive value of not less than a first predetermined value (at the time of forward  
25 stroke steering), while being determined

depending on the steering speed when the steering speed takes a value of less than the first predetermined value. At this time, the reference assist characteristics may not be shifted in the positive direction on the axis of coordinates of the steering torque, but may be exclusively shifted in the negative direction on the axis of coordinates of the steering torque. That is, the shifting amount may be determined such that its value in a case where the steering speed takes the first predetermined value is zero and such that it decreases monotonously (for example, in a stepped shape or linearly), as the steering speed decreases, to a negative lower-limit value with respect to the steering speed which is less than the first predetermined value. In the reference assist characteristics, therefore, a portion in a range of the steering torque taking the positive value is shifted toward the origin, so that the steering assist force increases, thereby making it possible to improve a spring feeling at the time of return stroke steering. The above-mentioned predetermined value may be determined to be not less than zero. If the first predetermined value is set to a positive value, however, the steering

assist force can be increased in a steering hold-on state where the steering speed becomes approximately zero, thereby making it possible to reduce a steering burden on a driver in the steering hold-on state. Further, in a return stroke steering state where the steering speed takes a negative value, the shifting amount may be variably set depending on the steering speed, or may be fixed to the negative lower-limit value irrespective of the steering speed.

In a case where the steering torque takes a negative value, the shifting amount may be made zero when the steering speed takes a negative value of not more than a second predetermined value, while being determined depending on the steering speed when the steering speed takes a value exceeding the second predetermined value. At this time, the reference assist characteristics may not be shifted in the negative direction on the axis of coordinates of the steering torque, but may be exclusively shifted in the positive direction on the axis of coordinates of the steering torque. That is, the shifting amount may be determined such that its value in a case where the steering speed takes a second predetermined value is zero and such

that it increases monotonously (for example, in a stepped shape or linearly), as the steering speed increases, to a positive upper-limit value with respect to the steering speed exceeding the second  
5 predetermined value. In the reference assist characteristics, therefore, a portion in a range of the steering torque taking the negative value is shifted toward the origin, so that the steering assist force increases, thereby making it possible  
10 to improve a spring feeling at the time of return stroke steering. The above-mentioned second predetermined value may be determined to be not more than zero. If the second predetermined value is set to a negative value, the steering assist  
15 force can be increased in a steering hold-on state where the steering speed becomes approximately zero, thereby making it possible to reduce a steering burden on a driver in the steering hold-on state. In a return stroke steering state where  
20 the steering speed takes a positive value, the shifting amount may be variably set depending on the steering speed, or may be fixed to a positive upper-limit value irrespective of the steering speed.

25       The motor driving target value is set in

accordance with the corrected assist characteristics thus obtained, so that different assist characteristics can be set at the time of forward stroke steering and at the time of return stroke steering. Consequently, a sufficient responsive feeling can be obtained at the time of forward stroke steering, and a sufficient steering assist force is transmitted to the steering mechanism at the time of return stroke steering, thereby making it possible to cancel such an undesirable steering feeling (spring feeling) that a steering wheel is returned to a neutral position more strongly than the driver intends. Moreover, at the time of forward stroke steering, a reference assist map is used as it is. Therefore, a steering burden does not vary depending on the steering speed, so that the reference assist map is easy to tune.

The electric power steering apparatus may further comprise a vehicle speed sensor for sensing the vehicle speed of the motor vehicle equipped with the electric power steering apparatus, and a vehicle speed adaptive shifting amount setting section for variably setting the shifting amount of the corrected assist

characteristics with respect to the reference assist characteristics depending on the vehicle speed sensed by the vehicle speed sensor.

In this configuration, the shifting amount of  
5 the reference assist characteristics can be  
variably set depending on the vehicle speed.  
Accordingly, this can cope with a case where it  
is not so necessary to correct the assist  
characteristics, for example, a steering  
10 operation at the time of a stop or at the time of  
low-speed traveling.

The electric power steering apparatus may  
further comprise a steering torque sensor for  
sensing the steering torque applied to the  
15 operation member (which may be shared with the  
above-mentioned operation amount sensor), and a  
steering torque adaptive shifting amount setting  
section for variably setting the shifting amount  
of the corrected assist characteristics with  
20 respect to the reference assist characteristics  
depending on the steering torque sensed by the  
steering torque sensor.

By this configuration, when the steering  
torque takes a small value in the vicinity of zero,  
25 for example, the shifting amount can be restrained

or reduced to zero. Consequently, it is possible to restrict steering assist in a very small steering torque range where no steering assist is required.

5       The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying  
10 drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing the electrical configuration of an electric power steering apparatus according to an embodiment of  
15 the present invention;

Fig. 2 is a diagram for explaining reference assist characteristics and corrected assist characteristics obtained by shifting the reference assist characteristics along the axis  
20 of coordinates of a steering torque;

Figs. 3 (a) and 3 (b) are diagrams showing the relationship of a reference shifting amount to a steering angular velocity;

Fig. 4 is a diagram for explaining variable  
25 setting of a shifting amount with respect to a

vehicle speed;

Fig. 5 is a diagram for explaining variable setting of a shifting amount with respect to a steering torque;

5 Fig. 6 is a flow chart for explaining processing related to driving control of an electric motor by a microprocessor; and

Fig. 7 is a diagram showing an example of assist characteristics.

#### 10 DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 is a block diagram showing the electrical configuration of an electric power steering apparatus according to an embodiment of the present invention. A steering torque applied  
15 to a steering wheel 1 serving as an operation member is mechanically transmitted to a steering mechanism 3 including a rack shaft through a steering shaft 2. A steering assist force is mechanically transmitted to the steering  
20 mechanism 3 from an electric motor M through a driving force transmitting mechanism such as a gear mechanism (a speed reduction mechanism) or a direct drive system.

The steering shaft 2 is divided into an input  
25 shaft 2A coupled to the steering wheel 1 and an



output shaft 2B coupled to the steering mechanism 3. The input shaft 2A and the output shaft 2B are connected to each other by a torsion bar 4. The torsion bar 4 causes distortion depending on the steering torque. The direction and the amount of the distortion are sensed by a torque sensor 5.

The torque sensor 5 is of a magnetic type, for example, for sensing a magnetoresistance which varies depending on the change in the positional relationship in the direction of rotation between the input shaft 2A and the output shaft 2B. An output signal of the torque sensor 5 is inputted to a controller 10 (ECU : Electronic Control Unit).

An output signal of a vehicle speed sensor 6 for sensing the traveling speed of a motor vehicle equipped with the electric power steering apparatus and an output signal of a steering angle sensor 7 for sensing the steering angle of the steering wheel 1 (e.g., a rotation angle of the input shaft 2A) are further inputted to the controller 10.

The controller 10 determines an assist torque target value to be given to the steering mechanism 3 from the electric motor M depending on a steering torque sensed by the torque sensor 5, a vehicle

speed sensed by the vehicle speed sensor 6, and an output of the steering angle sensor 7, in order to drive and control the electric motor M such that a steering assist force corresponding to the steering torque and the like is applied to the steering mechanism 3.

The controller 10 has a microprocessor 20 and a motor driver 30 for driving the electric motor M on the basis of a control signal from the microprocessor 20.

The microprocessor 20 comprises an assist torque target value setting section 21 which is a functional processing unit realized by executing program-based processing, and an assist characteristics storing section 22 composed of a storage area of a memory in the microprocessor 20. The assist characteristics storing section 22 stores a plurality of reference assist maps respectively corresponding to a plurality of reference assist characteristics previously determined with respect to a plurality of vehicle speed areas. The reference assist characteristics are obtained by determining reference characteristics of an assist torque target value corresponding to a steering torque, and the

reference value of the assist torque target value is stored in the assist characteristics storing section 22 in the form of an assist map (a table) in correspondence with the values of a plurality of steering torques.

The microprocessor 20 further comprises a steering angular velocity computing section 23 for computing a steering angular velocity on the basis of the output signal of the steering angle sensor 7, and a shifting amount computing section 24 for computing a shifting amount in a case where the reference assist characteristics are shifted along the axis of coordinates of the steering torque to obtain virtual corrected assist characteristics. The shifting amount computing section 24 computes a shifting amount for obtaining virtual corrected assist characteristics obtained by shifting the reference assist characteristics along the axis of coordinates of the steering torque on the basis of a steering angular velocity  $\omega$  computed by the steering angular velocity computing section 23, a vehicle speed  $V$  sensed by the vehicle speed sensor 6, and a steering torque  $T_h$  sensed by the torque sensor 5.

The assist torque target value setting section 21 reads out an assist torque target value  $T_a$  corresponding to the corrected assist characteristics from the assist characteristics storing section 22 on the basis of the steering torque  $T_h$  sensed by the torque sensor 5, the vehicle speed  $V$  sensed by the vehicle speed sensor 6, and a shifting amount  $\Delta T_h$  computed by the shifting amount computing section 24 (its sign represents a shifting direction, and its absolute value represents a shifting length). The motor driver 30 supplies a necessary and sufficient driving electric current to the electric motor  $M$  on the basis of the read assist torque target value  $T_a$ .

Fig. 2 is a diagram for explaining reference assist characteristics corresponding to the reference assist map stored in the assist characteristics storing section 22 and corrected assist characteristics obtained by shifting the reference assist characteristics along the axis of coordinates of the steering torque.

The steering torque  $T_h$  sensed by the torque sensor 5 takes a positive value when a torque for rightward steering is applied to the steering

wheel 1, while taking a negative value when a torque for leftward steering is applied to the steering wheel 1. The reference assist characteristics are indicated by a curve L0 in Fig. 2. The reference assist characteristics are so determined that a positive value of the assist torque target value  $T_a$  corresponds to the steering torque  $T_h$  taking the positive value, and a negative value of the assist torque target value  $T_a$  corresponds to the steering torque  $T_h$  taking the negative value. Although as described in the foregoing, the assist characteristics storing section 22 stores a plurality of reference assist maps corresponding to a plurality of vehicle speed areas, one reference assist characteristics applied in a certain vehicle speed area are illustrated in Fig. 2 for simplicity of illustration.

In the reference assist characteristics indicated by the curve L0, the assist torque target value  $T_a$  is set to zero irrespective of the value of the steering torque  $T_h$  in the vicinity of  $T_h = 0$ . Such a range of the steering torque is a dead zone NS.

In the present embodiment, the assist torque

target value  $T_a$  is set on the basis of virtual corrected assist characteristics (e.g., characteristics indicated by curves L11 and L12) obtained by shifting the reference assist

5 characteristics along the axis of coordinates of the steering torque  $T_h$  (in the positive direction or the negative direction) by the shifting amount  $\Delta T_h$  computed by the shifting amount computing section 24 on the basis of the steering angular

10 velocity  $\omega$  computed by the steering angular velocity computing section 23, the vehicle speed  $V$ , and the steering torque  $T_h$ .

However, the reference assist characteristics are shifted only in the negative

15 direction on the axis of coordinates of the steering torque  $T_h$  in situations where the steering torque  $T_h$  is not less than zero (see the curve L11), while being shifted only in the positive direction on the axis of coordinates of

20 the steering torque  $T_h$  in situations where the steering torque  $T_h$  takes a negative value (see the curve L12), as described below.

Figs 3 (a) and 3 (b) are diagrams for explaining the function of the shifting amount

25 computing section 24, where the relationship of

a reference shifting amount  $\Delta Th_B$  to a steering angular velocity  $\omega$ . The shifting amount computing section 24 multiplies the reference shifting amount  $\Delta Th_B$  by a vehicle speed gain  $G_v$  and a torque gain  $G_T$ , described later, to find a shifting amount  $\Delta Th$  ( $=G_v \times G_T \times \Delta Th_B$ ) .

The shifting amount computing section 24 has a memory storing a table corresponding to a curve (a polygonal line in this example) of the characteristics shown in Figs. 3 (a) and 3 (b), for example. The shifting amount computing section 24 determines the reference shifting amount  $\Delta Th_B$  in accordance with a table of characteristics shown in Fig. 3 (a) when the steering torque  $Th$  satisfies  $Th \geq 0$ , while determining the reference shifting amount  $\Delta Th_B$  in accordance with a table of characteristics shown in Fig. 3 (b) when the steering torque  $Th$  satisfies  $Th < 0$ .

In the table of the characteristics shown in Fig. 3 (a) applied when  $Th \geq 0$ , the reference shifting amount  $\Delta Th_B$  which is zero or negative is set in a range where the steering angle velocity  $\omega$  is not more than a first predetermined value  $\omega_1$  ( $>0$ ). More specifically, in a range where the

steering angular velocity  $\omega$  is not more the first predetermined value  $\omega_1$ , the reference shifting amount  $\Delta Th_B$  is so set as to decrease monotonously (linearly in the example shown in Fig. 3 (a)) using a lower-limit value  $\beta$  (where  $\beta < 0$ ) as a lower limit as the steering angular velocity  $\omega$  decreases. Contrary to this, in a range where the steering angular velocity  $\omega$  exceeds the first predetermined value  $\omega_1$ , the reference shifting amount  $\Delta Th_B$  satisfies  $\Delta Th_B = 0$  without depending on the steering angular velocity  $\omega$ .

On the other hand, in the table of the characteristics shown in Fig. 3 (b) applied when  $Th < 0$ , the reference shifting amount  $\Delta Th_B$  which is zero or positive is set in a range where the steering angular velocity  $\omega$  is not less than a second predetermined value  $\omega_2$  (where  $\omega_2 < 0$ . For example,  $|\omega_2| = \omega_1$ .) In the foregoing range, the reference shifting amount  $\Delta Th_B$  which is zero or positive is set. More specifically, in a range where the steering angular velocity  $\omega$  is not less than the second predetermined value  $\omega_2$ , the reference shifting amount  $\Delta Th_B$  is so set as to increase monotonously (linearly in the example shown in Fig. 3 (b)) using an upper-limit value



$\alpha$  (where  $\alpha < 0$ . For example,  $\alpha = |\beta|$ .) as an upper limit as the steering angular velocity  $\omega$  increases. Contrary to this, in a range where the steering angular velocity  $\omega$  is less than the second  
 5 predetermined value  $\omega_2$ , the reference shifting amount  $\Delta Th_B$  satisfies  $\Delta Th_B = 0$  without depending on the steering angular velocity  $\omega$ .

At the time of forward stroke steering in which the direction of the steering torque  $Th$  and  
 10 the direction of the steering angular velocity  $\omega$  coincide with each other (at the time of steering in a direction away from a steering angle midpoint), the reference shifting amount  $\Delta Th_B$  becomes zero. On the other hand, at the time of  
 15 return stroke steering in which the direction of the steering torque  $Th$  and the direction of the steering angular velocity  $\omega$  do not coincide with each other (at the time of steering in a direction nearer to the steering angle midpoint), the  
 20 reference shifting amount  $\Delta Th_B$  is so determined that the reference assist characteristics are shifted in a direction nearer to the origin along the axis of coordinates of the steering torque. Further, when the steering angular velocity  $\omega$   
 25 takes a value in the vicinity of zero ( $\omega_2 < \omega < \omega_1$ ),

the reference shifting amount  $\Delta Th_B$  is so determined that the reference assist characteristics are shifted in the direction nearer to the origin along the axis of coordinates of the steering torque.

In such a manner, at the time of forward stroke steering, the reference assist characteristics are not shifted. Therefore, a steering burden does not vary depending on the steering angular velocity, the reference assist characteristics can be easily tuned, and a sufficient responsive feeling can be given to a driver. On the other hand, at the time of return stroke steering and at the time of hold-on steering, a spring feeling at the time of return stroke steering can be canceled by shifting the reference assist characteristics toward the origin, and a good steering feeling can be realized by reducing a steering burden at the time of hold-on steering.

Fig. 4 is a diagram for explaining variable setting of a shifting amount  $\Delta Th$  corresponding to a vehicle speed  $V$ , and Fig. 5 is a diagram for explaining variable setting of a shifting amount  $\Delta Th$  corresponding to a steering torque  $Th$ . The shifting amount computing section 24 finds a

reference shifting amount  $\Delta Th_B$  in accordance with the characteristics shown in Fig. 3, and further multiplies the reference shifting amount  $\Delta Th_B$  by a vehicle speed gain  $G_V$  determined in accordance with characteristics shown in Fig. 4 and a torque gain  $G_T$  determined in accordance with characteristics shown in Fig. 5, to find a shifting amount  $\Delta Th (= \Delta Th_B \times G_V \times G_T)$ . The assist torque target value setting section 21 retrieves the reference assist map stored in the assist characteristics storing section 22 using the shifting amount  $\Delta Th$ , thereby reading out an assist torque target value  $T_a$  conforming to corrected assist characteristics which are virtually determined depending on a steering angular velocity  $\omega$ , a vehicle speed  $V$ , and a steering torque  $Th$ .

The vehicle speed gain  $G_V$  is so determined as to increase monotonously (linearly in this example) using a predetermined upper-limit value ("1" in the example shown in Fig. 4) as an upper limit as the vehicle speed  $V$  increases when the vehicle speed  $V$  is in a range from zero to a predetermined speed.

This can also cope with a case where the assist characteristics need not be so corrected, for

example, a steering operation at the time of a stop or at the time of low-speed traveling.

On the other hand, the torque gain  $G_T$  uses a region in the vicinity of the steering torque  $T_h = 0$  as a dead zone, and is so set as to increase monotonously (linearly in this example) using a predetermined upper-limit value ("1" in this example) as an upper limit as the absolute value of the steering torque  $T_h$  increases outside the dead zone. Consequently, steering assist in a range where no steering assist is required in the vicinity of the steering torque  $T_h = 0$  is restricted.

On the basis of the shifting amount  $\Delta T_h$  determined in the foregoing manner, the assist torque target value  $T_a$  is determined in accordance with virtual corrected assist characteristics obtained by shifting the reference assist characteristics by the shifting amount  $\Delta T_h$  along the axis of coordinates of the steering torque.

More specifically, when it is assumed that the reference assist characteristics are represented by  $T_a = f(T_h)$  using a function  $f$ , a value obtained by subtracting the shifting amount  $\Delta T_h$  from the steering torque  $T_h$  sensed by the torque sensor

is used as a steering torque value for assist map retrieval  $Th^*$  (that is,  $Th^* = Th - \Delta Th$ ), and the reference assist map stored in the assist characteristics storing section 22 may be  
5 retrieved using the steering torque value for retrieval  $Th^*$ . Consequently, the assist torque target value  $Ta$  ( $=f(Th^*)$ ) can be determined in accordance with the virtual corrected assist characteristics.

10 Fig. 6 is a flow chart for explaining the function of the microprocessor 20. The microprocessor 20 reads a vehicle speed  $V$  sensed by the vehicle speed sensor 6 and a steering torque  $Th$  sensed by the torque sensor 5 (steps S1 and S2).  
15 Further, an output signal of the steering angle sensor 7 is read, thereby finding a steering angular velocity  $\omega$  by the steering angular velocity computing section 23 (step 3). The shifting amount computing section 24 reads out a  
20 reference shifting amount  $\Delta Th_B$  corresponding to the found steering angular velocity  $\omega$  on the basis of the steering angular velocity  $\omega$  (step S4). Further, the shifting amount computing section 24 finds a vehicle speed gain  $G_v$  on the basis of the  
25 vehicle speed  $V$  sensed by the vehicle speed sensor

6 (step S5). Further, the shifting amount  
computing section 24 finds a torque gain  $G_T$  on the  
basis of the steering torque  $Th$  sensed by the  
torque sensor 5 (step S6). The shifting amount  
5  $\Delta Th$  is computed by multiplying the reference  
shifting amount  $\Delta Th_B$  by the vehicle speed gain  $G_v$   
and the torque gain  $G_T$  thus found (step S7).

The found shifting amount  $\Delta Th$  is given to the  
assist torque target value setting section 21. The  
10 assist torque target value setting section 21  
finds the steering torque value for retrieval  $Th^*$   
as  $Th^* = Th - \Delta Th$ , and retrieves the reference assist  
map stored in the assist characteristics storing  
section 22 on the basis of the steering torque  
15 value for retrieval  $Th^*$  (step S8).

In such a manner, an assist torque value  $Ta$   
conforming to virtual corrected assist  
characteristics obtained by shifting reference  
assist characteristics along the axis of  
20 coordinates of the steering torque by the shifting  
amount  $\Delta Th$  is read out of the assist characteristic  
storing section 22. The motor driver 30 is  
controlled on the basis of the read assist  
characteristic target value  $Ta$ , and the motor  $M$   
25 produces a driving force corresponding thereto,

to supply the produced driving force to the steering mechanism 3.

Although description has been made of one embodiment of the present invention, the present invention can be also embodied in another embodiment. Although in the above-mentioned embodiment, the vehicle speed  $V$  and the steering torque  $T_h$  are considered with respect to the shifting amount  $\Delta T_h$  of the assist characteristics, variable setting of a shifting amount dependent on the vehicle speed  $V$  and the steering torque  $T_h$  is not necessarily required. That is, the reference shifting amount  $\Delta T_{hB}$  in the above-mentioned embodiment may be used as it is as the shifting amount  $\Delta T_h$ , only the vehicle speed gain  $G_v$  may be multiplied by the reference shifting amount  $\Delta T_{hB}$  without using the torque gain  $G_T$  to find a shifting amount  $\Delta T_h$ , and only the torque gain  $G_T$  may be multiplied by the reference shifting amount  $\Delta T_{hB}$  without using the vehicle speed gain  $G_v$  to find a shifting amount  $\Delta T_h$ .

Although in the above-mentioned embodiment, the assist map corresponding to the reference assist characteristics is stored in the assist characteristics storing section 22, to read out

the assist torque target value  $T_a$  from the assist map, the assist torque target value  $T_a$  corresponding to the steering torque value for retrieval  $Th^*$  may be determined by a functional  
5 operation.

The same is true for the shifting amount computing section 24. The characteristics of the reference shifting amount  $\Delta Th_B$  corresponding to the steering angular velocity  $\omega$  may be previously  
10 stored in the memory, or the reference shifting amount  $\Delta Th_B$  corresponding to the steering angular velocity  $\omega$  may be found by a functional operation. The same is true for operations of the vehicle speed gain  $G_v$  corresponding to the vehicle speed  
15  $V$  and the torque gain  $G_T$  corresponding to the steering torque  $Th$ .

Although in the above-mentioned embodiment, description has been made using the assist torque target value as a motor driving target value and  
20 using the characteristics of the assist torque target value corresponding to the steering torque as assist characteristics, the present invention is not limited to the same. For example, a motor current target value or a motor voltage target  
25 value may be taken as a motor driving target value,



and the relationship between the steering torque and the motor current target value or the motor voltage target value may be taken as assist characteristics.

5        Furthermore, although in the above-mentioned embodiment, the steering angle sensed by the steering angle sensor 7 is subjected to time differential to compute the steering angular velocity, a counter- electromotive force produced  
10 between terminals of the electric motor M may be found on the basis of an output of a motor current detection circuit for finding a motor current flowing through the electric motor M and an output of a between-terminals voltage detection circuit  
15 for detecting a voltage between the terminals of the electric motor M without using a steering angle sensor, in order to estimate a steering angular velocity corresponding thereto.

Although the present invention has been  
20 described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the  
25 appended claims.

The present application corresponds to Japanese application NO. 2003-51539 filed with the Japanese Patent Office on February 27, 2003, the disclosure of which is hereinto incorporated by  
5 reference.